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Characterizing Stress in Feeder Cattle

G. LeRoy Hahn and John A. Nienaber[1 2 3]

Introduction

During the period August 6 to 10, 1992, a heat wave moved through central and eastern Nebraska. Maximum air temperatures were in the 90 to 95°F range, generally not considered to be extreme during the summer season. However, during this particular episode, the accompanying humidity was higher than normal (50 to 70% during the hottest portions of the day), with light to moderate winds except on August 8 when the wind was fairly strong. The relatively cool preceding summer weather had not adequately conditioned livestock to high levels of heat stress. As a result, several hundred feedlot cattle died in this area. Generally, animals most vulnerable to heat stress are new or recent arrivals in the feedlot, or those nearing market weight. Surviving cattle experience a reduced feed intake as a result of the heat stress which affects growth and efficiency.

The described heat wave is a vivid reminder: weather is a factor that cattle producers must deal with on a daily basis. Heat or extreme cold can reduce performance, health, and/or well-being. Those effects can be compounded by precipitation, wind, or poor nutrition in cold weather and high humidity in hot weather. An article, "Weather and Climate Effects on Beef Cattle," in the 1985 MARC Beef Research Progress Report No. 2 summarized some of the effects based on research observations, and discussed management alternatives for coping with adverse environments.

This report concerns measurement of stress in feeder cattle fed ad libitum. Objective characterization of stress is an essential element in determining the impact of environmental stressors, especially in establishing threshold limits (Figure 1) for reduced performance, health, or welfare. In passing, it is important to recognize that stress is an integral part of life. While usually considered a negative factor, it can also be a positive influence when it leads to coping and adaptation.

Blood hormone levels, such as cortisol, have typically served as stress response measures; however, blood sampling is an invasive technique which has limitations. We have recently investigated stress responses in terms of alterations in body temperature. In healthy animals, body temperature is an integration of heat-producing and heat-dissipating processes, and includes short- and long-term thermoregulatory responses to environmental stressors which ultimately affect animal performance. The focus of this report is on characterizing stress through analysis of the dynamics of body temperature fluctuations in feeder cattle. The results are used to examine stress thresholds.

Body temperatures reported here are represented by tympanic ("ear-drum") temperature requiring no surgery or other invasive procedures. Tympanic temperature has been shown in earlier research at MARC and elsewhere to be a sensitive measure of animal responses to environmental or disease-related challenges, as illustrated in Figure 2 for a cold-conditioned feedlot steer during a spring heat wave. Tympanic temperature represents the temperature of the hypothalamus, which plays a vital role in regulating endocrine and immune functions and is generally considered to have a central role in regulating feed intake.

Procedure

Tympanic temperatures were measured at 320-sec (1988) or 15-sec (1990) intervals in growing feeder cattle kept in nonstressing (cool) and heat-stressing (hot) environments at the MARC Environmental Laboratory. A silage-based diet was fed ad lib. A 2-wk cool period (50° + 12°F daily cyclic conditions) preceded each hot period. Each animal was exposed to several levels of daily cyclic hot conditions during successive treatment periods.

Various ways were evaluated to characterize the dynamics of the tympanic temperature responses to cool and hot conditions. The most successful method was a relatively new mathematical procedure called fractal analysis, which computes a fractal dimension as a measure of the "roughness" of the process analyzed. The method provides a value which objectively describes dynamic processes such as the animal's thermoregulatory system response to various environments.

Results

An example tympanic temperature record (15-sec measurement interval) is shown in Figure 3 for a steer during the last 2 days of exposure to nonstressing cool conditions and the first 6 days of exposure to heat. Some similarities are obvious in the overall response to hot conditions shown in Figure 3 for the laboratory steer and in Figure 2 for the feedlot steer. Similarities are especially strong for the diurnal range and pattern of body temperature rhythms and the daily declines in maximum and minimum body temperature during acclimation to heat.

Measurements obtained from the laboratory steer in controlled, repeatable daily cycles of temperature and humidity clarify the animal's response to the onset of hot conditions. Figure 3 shows the dynamics of the adaptive response and associated feed intake when the day-to-day variability of the outdoor environment is removed. The initial (acute) response to hot conditions requires about 3 days for the animal to regain a measure of balance between the metabolic heat production and the ability to dissipate heat. During this time, the lag between air temperature and body temperature is reduced; in the Figure 3 illustration, the lag reduced to about 3 to 4 hr after 3 days. Also after 3 days, maxima and minima for the tympanic temperature cycles steadily decreased during the acclimation phase, while feed intake tended to rebound somewhat. Measurements on all animals in the two experiments followed similar patterns, with the peaking of tympanic temperature typically occurring on the 3rd or 4th day after onset of heat. More extended datasets show that after about 7 or 8 days of exposure to heat, thermoregulation enters a chronic stage where the tympanic temperature cycles about a higher average value (depending on how hot the air temperature is) than during cool conditions. Feed intake is approximately an inverse situation, with the amount consumed at a reduced level in the chronic stage.

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[1]Hahn is the research leader, and Nienaber is an agricultural engineer, Biological Engineering Research Unit, MARC.

[2]This article is based on a published report in the Journal of Thermal Biology 17(2):115-120 (1992).

[3]Invaluable technical assistance was provided during this research by Roger Eigenberg, Dr. Yud-Ren Chen, Dr. Anne Parkhurst, and Dr. Tim McDonald. Technical support during the experiments by Lynn Gose, Eldon Shetler and Neal Kreutz, and the assistance of Elda Peterson in manuscript preparation, are also acknowledged.

The results in Figure 3 also illustrate the fine detail of thermoregulatory responses obtained from the 15-sec sampling interval, which shows the very distinct differences in tympanic temperature patterns for an animal exposed to nonstressing and stressing temperatures. The short-term dynamic variations of tympanic temperature about the underlying daily cycles are considerably "rougher" during cool conditions than during hot conditions which challenge the animal's thermoregulatory system.

The "roughness" of tympanic temperature responses to each condition was analyzed by computing fractal dimensions, as discussed in the Procedure section. Table 1 summarizes fractal dimension (D) results for available tympanic temperature data from three steers exposed to five temperatures in the 1988 test (320-sec recording intervals), and Table 2 provides averaged D-values and variances for six steers exposed to four temperatures in the 1990 test (15-sec recording intervals). Dataset A in Table 2 includes D-values computed from tympanic temperature records throughout the exposures to the various air temperatures, while Dataset B is limited to records during the chronic stages of exposure to each temperature. Results in these tables show that:

1. Fractal dimensions can be used to objectively classify thermoregulatory responses to cool and hot environments when based on tympanic temperatures recorded at intervals of 5 to 10 minutes.
2. Using tympanic temperature recording intervals of 15 sec does not provide distinctions among fractal dimensions for the various environments; other analyses show the effect to be true up to sampling intervals of 150 seconds.

The reason(s) for the apparent effect of sampling interval on fractal dimension are not yet clear, but may be related to short-term biological changes (such as vascular blood flow) or a limitation of the fractal technique. Given this possible limitation, the computation of fractal dimensions from tympanic temperatures recorded at intervals of 5 to 10 min provides a new approach to characterizing animal stress. The method provides results which are reasonably robust and repeatable across time and across animals. Further, the approach is particularly beneficial since it is based on a noninvasive measure which can be recorded without disturbance of normal animal routines and without human intervention.

Further research into practical application of fractal dimensions to characterize stress is planned in several areas. The first is to establish how well the laboratory-derived characterizations of stress responses can be related to field situations for a variety of environments. Initial observations from cattle in naturally varying cool and hot environments indicate computed fractal dimensions are consistent with those from laboratory data. A second area involves further evaluation of differences in fractal dimensions over time in the same animals (including the possibility of interacting stressors such as nutritional status). Observed differences among individual animals may provide a basis for genetic selection for tolerance to heat or other stressors. Evaluation of the approach to measure responses to other types of stressors (such as handling and transport) is a third area. A fourth area, the one which we initially targeted as a basis for this research, is further evaluation of threshold limits for stress as described in Figure 1. An example of using results of the fractal analysis for threshold definition is described in the next section.

Biological thresholds. Objective classification of stressors provides the basis for examining stress thresholds in growing animals. Using the information from Table 1 as an example, a plot of the fractal dimension, D, as a function of the average environmental temperature (Fig. 4) shows a threshold for reduced D values at about 77°F for growing cattle fed ad libitum. Values from Table 2 further support a threshold near 77°F. This indicates that for our experimental animals in thermal environments without exposure to strong radiant loads, the threshold limit for coping, above which performance is likely to be reduced, is about 77°F. It is interesting that these same experimental animals had a coincident feed intake decline threshold at 77°F. The association between tympanic temperature and feed intake thresholds is further strengthened by subsequent research we have done showing a strong linkage between feeding events and tympanic temperature.

Summary

Analyses of tympanic temperature data obtained as a measure of thermoregulatory function in feeder cattle fed ad-libitum indicate that responses to thermoneutral and several levels of heat-stressing environments can be objectively characterized by computed fractal dimensions. Variations in fractal dimensions resulting from thermal environment influences were greater than variations among animals.

There are apparently some biologically based limitations on sampling interval frequency for tympanic temperature as a basis for computed fractal dimensions. Intervals shorter than 2 1/2 min are generally unacceptable for characterizing responses, while intervals between 5 and 12 1/2 min are acceptably definitive. Using a 5 1/3 min sampling interval, a clearly defined fractal threshold was observed at about 77°F, indicating thermoregulatory stress above that temperature. This threshold is coincident with a threshold for feed intake decline, strengthening a previously noted linkage between thermoregulatory function and feed intake.

Other potential benefits of the fractal analysis technique include evaluating thermoregulatory responses to other types of stressors, and for estimating heat tolerance of animals as a basis for genetic selection to improve performance, health, and well-being of livestock in hot climates.

Table 1 – Fractal dimensions of the tympanic temperature of steers in nonstressing and stressing environmental temperatures—from 1988 data recorded at 320-sec intervals

Environmental temperature (°F)	Computed fractal dimension			
	Animal ID 3382	Animal ID 3456	Animal ID 3472	Average
50 ± 12	1.76	1.78	1.77	1.77
79 ± 12	1.74	1.66	N/A	1.70
82 ± 12	1.64	1.42	N/A	1.53
86 ± 12	1.61	1.45	1.34	1.47
93 ± 12	1.28	N/A	N/A	1.28

N/A = not available

Table 2 – Fractal dimensions of the tympanic temperatures of steers in nonstressing and stressing environmental temperatures-from 1990 data recorded at 15-sec intervals

	Computed fractal dimension ± standard deviation		
	Dataset A		Dataset B
Environmental temperature (°F)	Based on all 15-sec interval data pts in daily record	Based on sampling 15-sec dataset every 20th point (300-sec intervals)	Based on sampling 15-sec dataset every 40th point (600-sec intervals)
50 ± 12	1.73 (24)*	1.78 (20)	1.77 (42)
86 ± 12	1.69 (16)	1.69 (14)	1.55 (28)
90 ± 12	1.69 (16)	1.51 (16)	1.37 (28)
93 ± 12	1.72 (15)	1.44 (13)	1.35 (28)

*Parenthetical numbers are the steer-days of record used from the 6 steers in the experiment.

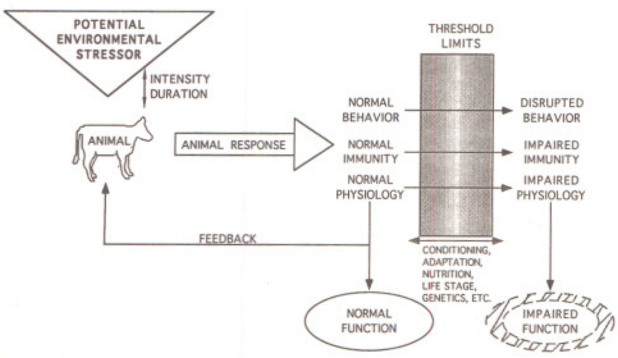

Figure 1—Responses of animals to potential environmental stressors which can influence performance and health.

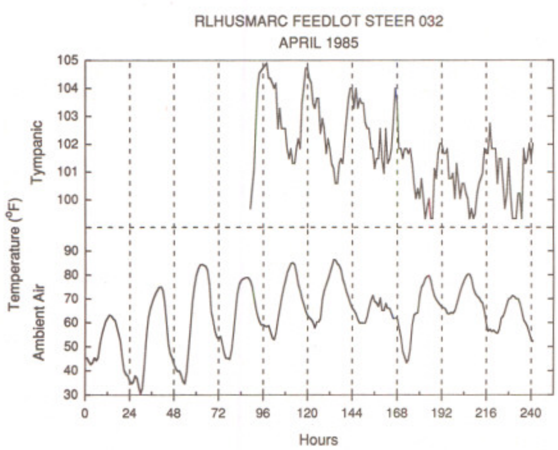

Figure 2—Tympanic temperatures recorded from a MARC feedlot steer for several days during a spring heat wave (records are at hourly intervals, with Hour 0 = midnight). Air temperatures for the period preceding the tympanic temperature record are provided to show the progression of the heat wave. Noteworthy points are 1) the hyperthermic (high) body temperatures recorded in an animal conditioned to cold temperatures; 2) the daily declines in maximum and minimum body temperature as the animal acclimates to the heat; 3) the return to normal cycles and ranges of body temperature as the heat wave abates; and 4) the 6 to 12 hr lag time between maximum and minimum air temperature and the subsequent body temperature, with maximum body temperatures occurring near midnight.

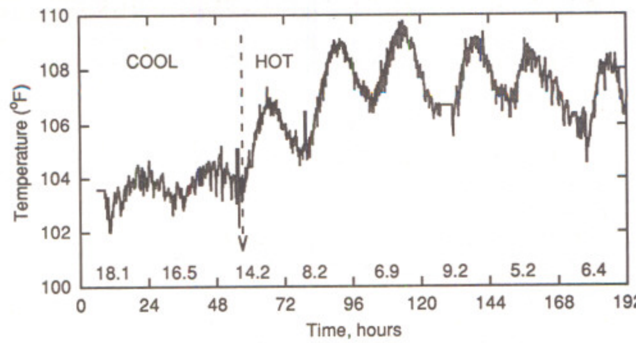

Figure 3—Tympanic temperatures recorded over several days from a steer exposed to moderate (50° ± 12°F) and hot (93° ± 12°F) environments. The arrow indicates the time at which the hot conditions were imposed. Midnight of each day occurred at the listed 24-h multiples. Daily feed intakes (lb) associated with each day are included.

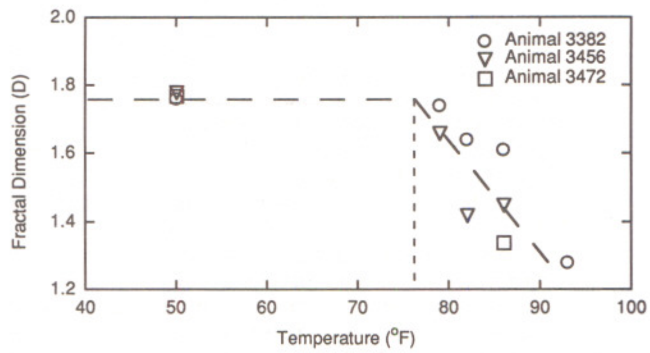

Figure 4—Plot of fractal dimension D (computed from tympanic temperatures of steers in cool and hot environments) as a function of environmental temperature. The intersection of lines for animals in stressed and unstressed states occurs near 77°F, indicating the threshold for onset of stress to be about that temperature.